Bulletin of Electrical Engineering and Informatics
Vol. 3, No. 4, December 2014, pp. 259~264
ISSN: 2089-3191

Implementation of Buck-Boost Converter with Coupled Inductor for Photo-Voltaic System

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Abstract

The solar energy is a very interesting alternative on supplement the electrical system generation. In this paper, a photovoltaic based system is obtained from a boost cascaded with a buck converter along with Coupled inductor. Due to its novel operating modes, high efficiency can be achieved because there is only one switch operating at high frequency at a time, and the converter allows the use of power MOSFET and ultra-fast reverse recovery diode. This paper begins with theoretical analysis and modeling of this boost–buck converter. The model indicates that the coupled inductance will lead to an increase in the gain and the decrease in ripples. Finally, this paper analyzes and describes step by step the process of designing, and simulation of high efficiency low ripple voltage buck boost DC-DC converter for the photovoltaic solar conversion system

Keywords: *coupled inductor, photovoltaic (PV), Maximum power point tracking (MPPT)*

1. Introduction

The solar energy conversion system is very interesting alternative on supplement the electric system generation. Depending on the characteristics of the PV panels, the total output voltage from the PV panels varies greatly due to different temperature, irradiation conditions, and shading and clouding effects. Thus, the input voltage of a residential PV inverter can vary widely, and can be quite different from the desirable level. Therefore, a dc–dc converter with either step-up function or step-down Function or even both step-up and step-down functions is needed Even though, many non-isolated single-stage buck–boost converter Topologies have been developed, their major drawbacks are limitation of input-voltage range and/or requirement of two input sources. With recent changes in electric code that allows ungrounded PV panels, it is possible to replace the isolated dc–dc with non-isolated or transformerless dc–dc. Without the transformer, the dc–dc stage will be more reliable and cost effective. The existing converter has boost inductance for easier control and stability as shown in Figure 1.

In order to obtain the low ripple, maximum voltage and power Buck-boost converter wit coupled inductor is proposed. Buck-boost converters are especially useful for PV maximum power tracking purposes, where the objective is to draw maximum possible power from solar panels at all times, regardless of the load. The output power is compared with the previous module output power and the duty cycle of the converter is adjusted continuously to track MPP. This process repeats until the output power reaches near to the maximum power point. The proposed model of converter which is implemented here is as shown in Figure 2.

In this paper, a boost–buck-type dc–dc converter is proposed with coupled inductor. Since the circuit runs either in boost or buck mode, it can be very efficient if the low conduction voltage drop power MOSFET and ultrafast reverse recovery diode are used. Since only the boost dc–dc converter or buck dc–dc converter operates with high-frequency switching all the time in the proposed system, the efficiency is improved.

Received September 6, 2014; Revised November 5, 2014; Accepted November 25, 2014

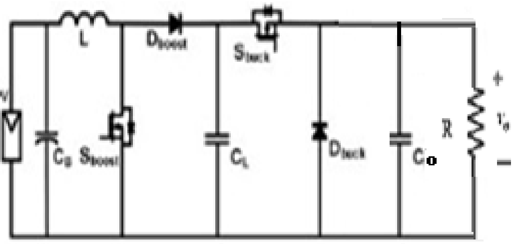


Figure 1. Boost–buck-based PV system

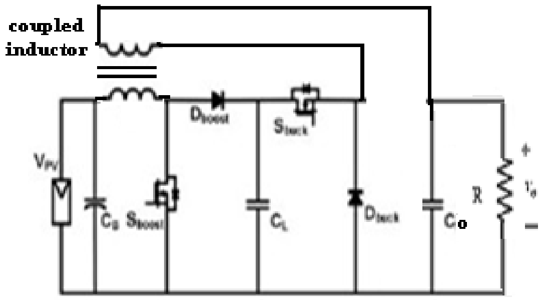
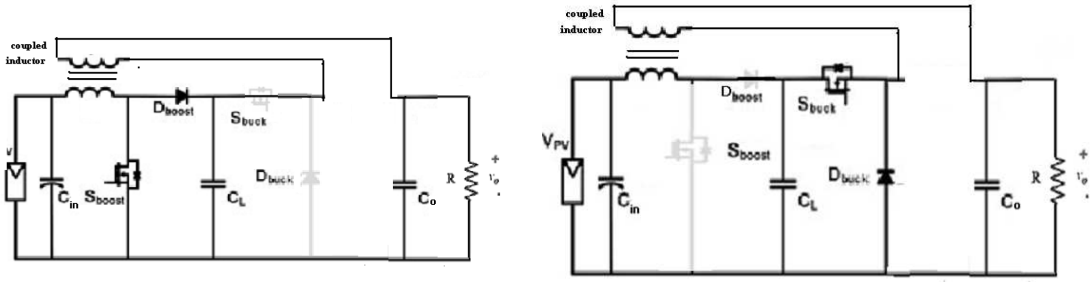


Figure 2. Boost–buck-based PV system with coupled inductor



(a). (b).

Figure 3. Operation Principle Modes: (a). Boost mode, (b). Buck mode

2. Operation Principle

A. Boost Mode:

When the PV panel's voltage is lower than the required output voltage, it will operate in boost mode, in which Sboost will be switched ON and OFF and Sbuck will be always ON, and the buck part of the circuit will act as an output filter as shown in Figure 3(a).
In this mode, the duty cycle of Sboost can be found as

$$\text{DUTY CYCLE (Sboost)} = 1 - \frac{\text{Vin}}{\text{Vo}} \tag{1}$$

B. Buck Mode:

When the PV panel's voltage is higher than the required output voltage, it will operate in buck mode, in which Sbuck will be switched ON and OFF and Sboost will be always OFF, and the Sboost part of the circuit will act as an input filter as shown in Figure 3(b).

In this mode, the duty cycle of Sbuck can be found as

$$\text{DUTY CYCLE (Sbuck)} = \frac{\text{Vo}}{\text{Vin}} \tag{2}$$

If the PV panel's voltage is higher than the peak output voltage, it will always run at buck mode.However if the PV panel's voltage is lower than the peak output voltage, the voltage across the capacitor C_L in boost/buck PV converter varies with the output voltage as shown in Figure 4. However, if PV panel's voltage is higher than peak output voltage, C_L's voltage will be the same as the PV panel's voltage.

3. System Description

The proposed PV system is shown in Figure 5. It consists of a PV array that converts solar energy to electrical energy.

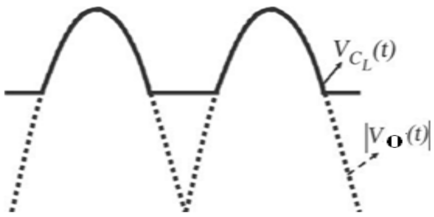


Figure 4. capacitor C_L's voltage

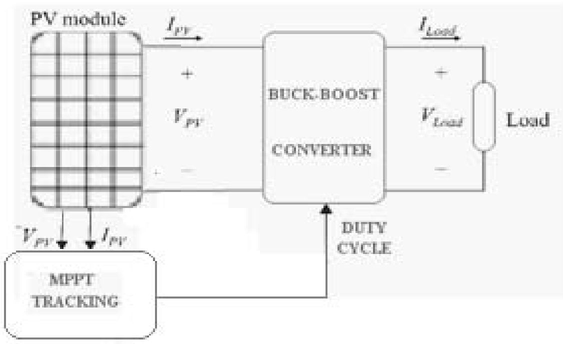


Figure 5.Proposed PV system

A DC/DC that converters dc voltages produced by the PV array to a required dc voltage. To obtain a stable voltage from an input supply (PV cells) that is higher and lower than the output, a high efficiency and minimum ripple DC-DC converter required in the system. Buck-boost converters make it possible to efficiently convert a DC voltage to either a lower or higher voltage. Buck-boost converters are especially useful for PV maximum power tracking purposes, where the objective is to draw maximum possible power from solar panels at all times, regardless of the load. The output power is compared with the previous module output power and the duty cycle of the converter is adjusted continuously to track MPP. This process repeats until the output power reaches near to the maximum power point. There are many methods have been developed to determine MPPT for a particular insolation value. Among them Perturb & Observe method has drawn much attention due to its simplicity and better results.

4. Photo Voltaic Cell

The simplest solar cell model as shown in Figure 6 consists of diode and current source connected parallelly. Voltage source and the parallel resistance Rpv constitute the current source.

I_L= Vpv/Rpv

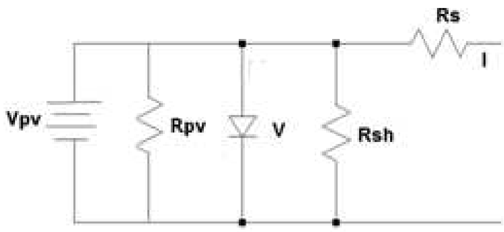


Figure 6. Solar cell model with serial and parallel resistance

Current source current is directly proportional to the solar radiation. Diode represents PN junction of a solar cell. Equation of ideal solar cell, which represents the ideal solar cell model, is:

$$I = I_L - I_s\left(e^{\frac{V}{n \cdot V_T}} - 1\right) \quad (3)$$

I_L - light-generated current (A), I_s - reverse saturation current (A)(aproximate range 10^{-8} A/m^2) V - diode voltage (V), V_T - thermal voltage (see equation below), V_T = 25.7 mV at 25°C n - diode ideality factor = 1...2 (n = 1 for ideal diode) Thermal voltage V_T (V) can be calculated with the following equation:

$$V_T = \frac{k \cdot T}{q} \quad (4)$$

k - Boltzmann constant = $1.38 \cdot 10^{-23}$ J/K,
T - temperature (K)
q - charge of electron = $1.6 \cdot 10^{-19}$ As

5. Maximum Power Point Tracking

The efficiency of a solar cell is very low. In order to increase the efficiency, methods are to be undertaken to match the source and load properly. One such method is the Maximum Power Point Tracking (MPPT). This is a technique used to obtain the maximum possible power from a varying source. This is done by utilizing a boost-buck converter whose duty cycle is varied by using a mppt algorithm. Important factors to consider when choosing a technique to perform MPPT are the ability of an algorithm to detect multiple maxima, costs, and convergence speed. The maximum power point is maintained using the perturb and observe MPPT technique.

Perturb and Observe

In this algorithm a slight perturbation is introduced in the system. Due to this perturbation, the power of the module alters. If the power enhances due to the perturbation, then the perturbation is carried on in that direction. After the maximum power is accomplished, the power at the next instant decrements and hence the perturbation reverses. Among different maximum power point tracking algorithms, the perturb and observe algorithm is elementary and also gives desirable results, as Figure 8. This algorithm is chosen and certain changes are made in the current work. The algorithm takes the values of current and voltage from the solar photovoltaic module. Power is computed from the assessed voltage and current.

The values of voltage and power at kth instant are put in. Then next values at (k+1)th instant are measured again and power is calculated from the measured values. The power and voltage at (k+1)th instant are subtracted with the values from previous instant. If we detect the power voltage curve of the solar photovoltaic module we see that in the right hand side curve where the voltage is almost constant the slope of power voltage is negative (dP/dV<0) where as in the left hand side the slope is positive and dP/dV>0. The right side curve is for the lower duty cycle (nearer to zero) whereas the left side curve is for the higher duty cycle (nearer to unity). Depending on the sign of dP(P(k+1) - P(k)) and dV(V(k+1) -V(k)) after subtraction the algorithm decide whether to increase the duty cycle or to reduce the duty cycle. The algorithm is elementary and has only one loop

6. Simulations

To validate the performance of the proposed system, simulations are performed using MATLAB/Simulink. The results of the proposed system are shown.The simulation circuits done in MATLAB/Simulink is as shown in Figure 8. In the Boost mode of operation of converter, for the PV panel's output voltage of 30V as shown in Figure 9(a), the output power and voltage are shown in Figure 9(b).

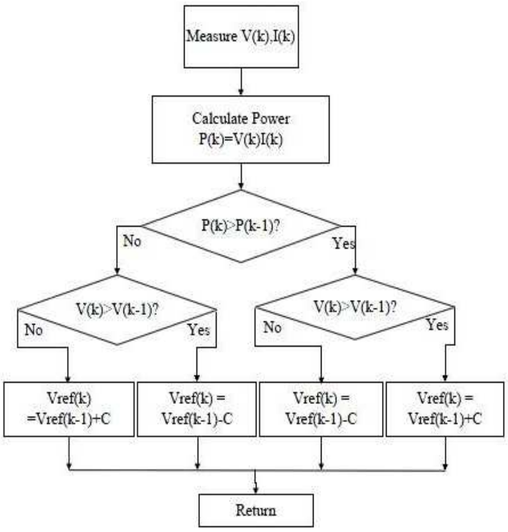


Figure 7. Flowchart for P&O method

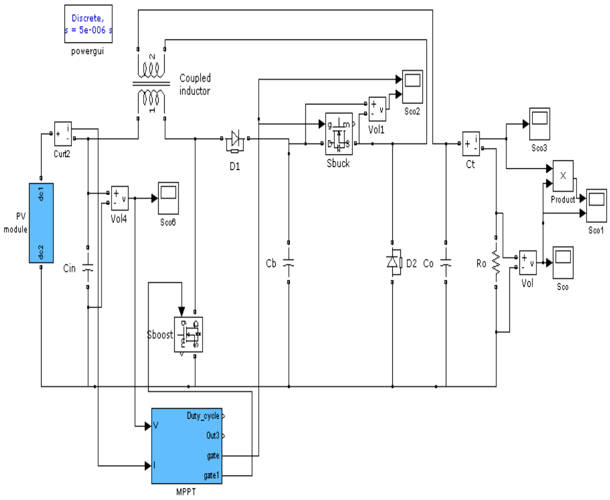
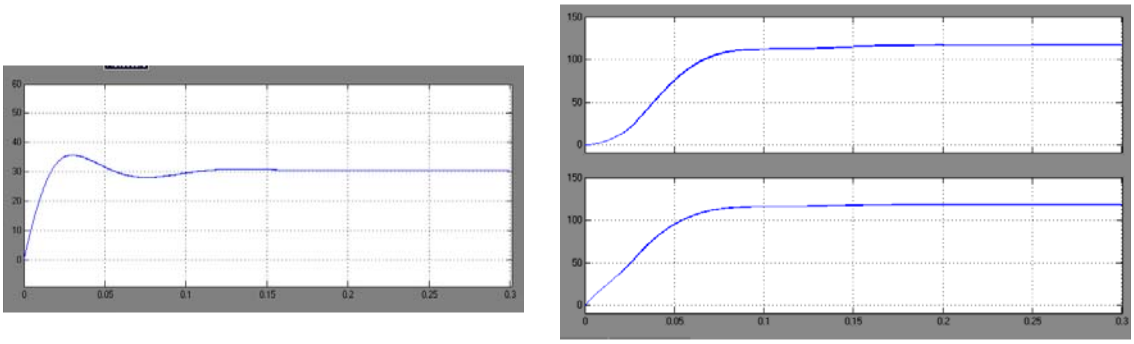


Figure 8. Simulation circuit of PV system



(a).

(b).

Figure 9. Boost mode of operation of converter; (a). PV panel output voltage, (b). Converter output & power in Boost mode

For the PV panel's output voltage of 100V as shown in Figure 10(a), the output power and voltage are shown in Figure 10(b).

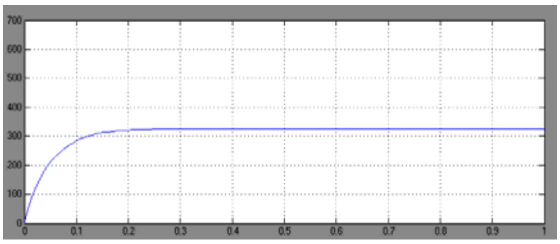


Figure 10(a). PV panel output votage

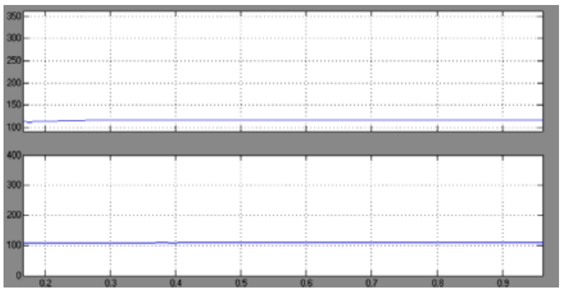


Figure 10(b). Converter output & power in Buck mode

Figure 10. PV 100V; (a). PV panel output votage, (b). Converter output & power in Buck mode

7. Conclusion

The implementation of a highly efficient PV based on a boost-cascaded-with-buck converter has been presented. The converter operates in either boost or buck mode, so high efficiency can be achieved. The use of coupled inductor increases the output power as well as output voltge which are the ripple free. The proposed circuit has been designed and simulated. Finally, the results indicate that the output voltge of the proposed solution is maintained as 100V.

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